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The ESM green components

A dedicated focus on the production of the green in the European Settlement Map's workflow

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Abstract

The European Settlement Map (ESM) is the first European Map of built-up which was published in July 2014. A new version of this information layer has been produced recently (15th April 2016) offering more detailed information (higher resolution) and improvement of green components.

The technology used to produce both ESM products is based on the Global Human Settlement Layer 2013 (GHSL) methodology, which has been adapted and tuned on the Copernicus core 003 dataset.

The ESM products have been financed by the Directorate-General for Regional and Urban Policy (DG REGIO) in the frame of the URBA project [WPK Id 1193]. The urban green component is an added value of the project. This information exploits the spectral characteristics of the Core 003 dataset.

In early prototypes of the ESM a modified NDVI index has been used as one of the main image-derived information for estimation of the built-up area. The produced built-up layer has been complemented with residual vegetation information.

In the ESM community this complementary information arouse interest in spite of its limitations. The high resolution of these information enables a variety of urban applications at urban scale.

In the response to the growing interest in urban green within community, the new version of the ESM proposes an improved green component. This report describes how this green component has been produced.

1. Introduction

DG REGIO and the JRC signed an administrative arrangement on 19th December 2012 with the objective of derive built-up related information from high resolution satellite data using the GHSL tool for integration in the European Urban Atlas (project URBA) [WP Id 1193].

The GHSL tool refers to a framework developed by the JRC since 2001 based on calculation of anisotropic rotation-invariant textural grey-level co-occurrence measures, also called PANTEX [1] later combined with a morphological image features extraction [2].

The GHSL, published in 2013 [3], tries to establish a method to answer to the following questions: where are settlements, buildings and hence population? What are the physical characteristics of settlements that allow inferring the number of people and quality of live and vulnerability? Global/regional actors need global/regional assessments or local assessments with globally consistent approaches (comparable)?

There is a big gap between the need of information and existing datasets (global/regional) about human settlements. Different scales of representation in different places of the world, too coarse detail of globally available layers in detection of built-up structures, semantic abstraction difficult to make interoperable and too expensive production process at detailed scales (1:10K-1:50K) make complicate the use or comparison between them [3].

The GHSL published in November 2012 addressed these issues and processed **16.736** images from heterogeneous sources ranging from 0.5m to 10m of spatial resolution, **300** of which in Europe (*Figure 1*).

Figure 1-European data availability 2012

By the end of December 2012, within the project URBA, we have been provided with a European complete and homogenous dataset of **3800** satellite images with 2.5-meter resolution and with bands NIR, RED and GREEN [4] (*Figure 2*).

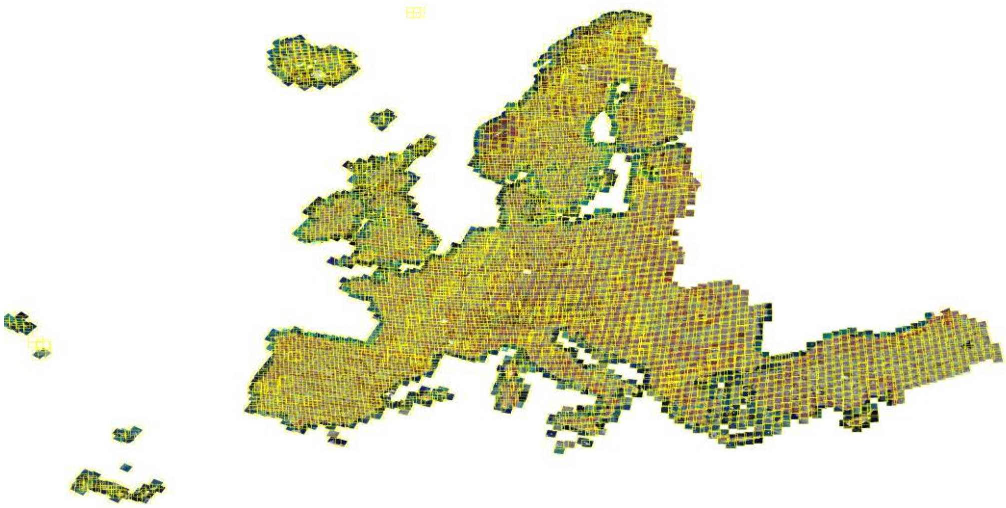

Figure 2-European data availability 2014

Thanks to the homogeneity of the input data we have been able to increase the quality of the ESM by adapting the GHSL method.

In the first implementation of the ESM on the new dataset, we focused on the customization of morphological parameter that guides the built-up extraction process. As the morphological operation uses panchromatic images as an input, the available spectral information was merged to produce a radiometric feature, called luminance [5]. The luminance was used to run the GHSL method as described in [6, 7].

We approached the use of spectral information implementing a vegetation layer based on a NDVI modified index. We experimented the effect of masking the luminance with the vegetation layer before the textural and morphological feature extraction, but it introduced more noises in the output features due to the contrast on the border of the mask. So the vegetation was not used to mask the luminance but it has reintroduced after the morphological stage/step in order to refine the classification of the non-built-up class.

The green component is not a primary product of the GHSL product, therefore the time and effort spent on the NDVI has been very little until now because of secondary importance respect to the built-up.

This report does not address the quality of the produced NDVI or green component. A more detailed report is dedicated to this aspect. Here, we describe the method used to derive the vegetation layer using the spectral information available and how it is integrated in the final classified ESM 2.5 and the aggregated 10m version.

The assumptions used in this work are derived from empirical evidences. This is the first report that systematically review the topic.

2. Method

Although several vegetation indices exist, we choose to use the NDVI because it is widely researched and considered a proper index for extracting vegetation [8].

NDVI values range from +1.0 to -1.0 (Table 1). Areas of barren rock, sand, or snow usually show very low NDVI values (for example, 0.1 or less). Sparse vegetation such as shrubs and grasslands or senescing crops may result in moderate NDVI values (approximately 0.2 to 0.5). High NDVI values (approximately 0.6 to 0.9) correspond to dense vegetation such as that found in temperate and tropical forests or crops at their peak growth stage [9].

Table 1 . *NDVI Values and related kind of vegetation*

NDVI values (+1.0 to -1.0)	
NDVI < 0.1	Barren rock, sand, or snow
0.2 < NDVI < 0.5	Sparse vegetation such as shrubs and grasslands or senescing crops
0.6 < NDVI < 0.9	Dense vegetation

Because of the manipulation of input satellite data source (pan sharpening) and of missing metadata information, the NDVI does not result in the expected value range. Often negative values can be found in dense vegetated areas.

Consequently, we experiment an empirical index that we called pseudo NDVI (NDVIx).

2.1. The pseudo NDVIx

The green component, introduced in [6, 7], is calculated using a pseudo NDVI index as:

$$NDVIx = \frac{NIR - L}{NIR + L} \ [1]$$

where *NIR* is the available near infrared band and *L* is the luminance.

The luminance enhances the contrast between built-up and non-built-up. The assumption here is that the built-up structures are the most shining features in the optical bands domain (B) [5]. The luminance calculated as:

$$L = @\max_{z=1,\dots,Z}(\beta_z) \ \forall x_{ij} \ \in \ \beta_z : \ x_{ij} \ \in \{0,1,\dots,255\} \ \subset \ \mathrm{Z}. \ [2]$$

While the use of NDVI (with the bands NIR and RED) is widely known and discussed in literature [8, 10] this modified version (using luminance instead of RED) is an empirical solution to enhance the built-up detection and shift the focus on built-up structure.

After its calculation, the NDVIx is linearly rescaled and casted to uint8 using the following Matlab code:

```
NDVIx=uint8 (imrscl (NDVIx,-2,+2)*99+1 [3]
```

Where *imrscl* is a linear rescale function.

```
function [ out ] = imrscl( im, min, max)      [4]
          im = single(im);                     [5]
          out = min(max(im,min),max);          [6]
          out = (out - min);                   [7]
          out = out /(max-min);                [8]
          out(isnan(im)) = NaN;                [9]
end                                            [10]
```

In the $NDVI\mathrm{x}$ small structures of 5 pixels by 5 pixels are extracted and enhanced using a top-hat morphological operation:

$$\mathrm{T}_{\omega}(\mathrm{NDVIx}) = \mathrm{NDVIx} - \mathrm{NDVIx} \circ \mathrm{b} \ [11]$$

where b is a structuring element of 'square' type and size of 5 pixels, and o denotes the opening operation. In mathematical morphology and digital image processing, top-hat transform is an operation that extracts small elements and details from given images. There exist two types of top-hat transform, here we apply the white top-hat transform defined as the difference between the input image and its opening by a structuring element.

The enhanced structure (the small extracted elements) are then added back to the ndvix as follow:

$$\mathrm{NDVIx} = \mathrm{NDVIx} + \mathrm{T}_{\omega}(\mathrm{NDVIx}) \ [12]$$

Finally, we apply a threshold to extract the vegetation (VEG), as explained in the following paragraph.

2.2. The threshold

The most interesting kind of urban green is the vegetation, which can either be sparse vegetation (shrubs and grasslands) or trees [10]. Often this urban vegetation is mixed with a variety of types of terrain which generally present lower NDVI values. Each of the 3800 scenes needs a different threshold and this implies or a long manual work or an automatic mechanism to estimate it. We used the Corinne Land Cover (CLC) reference layer to estimate the correct threshold for each scene. We firstly evaluate the presence of CLC's classes in a number of scenes; secondly we calculated the zonal mean NDVI in each CLC's class.

***Table 2** . shows the presence of the CLC classes over a sample of 600 scenes*

Agricultural areas	**94%**	Arable land	**82%**	Non-irrigated arable land	**82%**
				Permanently irrigated land	**0%**
				Rice fields	**3%**
		Heterogeneous agricultural areas	**94%**	Agro-forestry areas	**15%**
				Annual crops associated with permanent crops	**53%**
				Complex cultivation patterns	**82%**
				Land principally occupied by agriculture, with significant areas of natural vegetation	**88%**
		Pastures	**65%**	Pastures	**65%**
		Permanent crops	**59%**	Fruit trees and berry plantations	**38%**
				Olive groves	**56%**
				Vineyards	**53%**
Artificial surfaces	**91%**	Artificial, non-agricultural vegetated areas	**59%**	Green urban areas	**18%**
				Sport and leisure facilities	**59%**
		Industrial, commercial and transport units	**71%**	Airports	**29%**
				Industrial or commercial units	**68%**
				Port areas	**18%**
				Road and rail networks and associated land	**44%**
		Mine, dump and construction sites	**56%**	Construction sites	**18%**
				Dump sites	**12%**
				Mineral extraction sites	**56%**
		Urban fabric	**88%**	Continuous urban fabric	**44%**
				Discontinuous urban fabric	**88%**
Forest and semi natural areas	**100%**	Forests	**94%**	Broad-leaved forest	**94%**
				Coniferous forest	**79%**
				Mixed forest	**79%**
		Open spaces with little or no vegetation	**76%**	Bare rocks	**41%**
				Beaches, dunes, sands	**50%**
				Burnt areas	**0%**
				Glaciers and perpetual snow	**0%**
				Sparsely vegetated areas	**53%**
		Scrub and/or herbaceous vegetation associations	**100%**	Moors and heathland	**0%**
				Natural grasslands	**71%**
				Sclerophyllous vegetation	**65%**
				Transitional woodland-shrub	**82%**
NODATA	**0%**	NODATA		NODATA	**0%**
UNCLASSIFIED	**0%**	UNCLASSIFIED		UNCLASSIFIED	**0%**
UNCLASSIFIED		UNCLASSIFIED LAND SURFACE		UNCLASSIFIED LAND SURFACE	**0%**
UNCLASSIFIED		UNCLASSIFIED WATER BODIES		UNCLASSIFIED WATER BODIES	**0%**
Water bodies	**76%**	Inland waters		Water bodies	**50%**
				Water courses	**35%**

		Marine waters	Coastal lagoons	**9%**
			Estuaries	**0%**
			Sea and ocean	**47%**
Wetlands	**35%**	Inland wetlands	Inland marshes	**29%**
			Peat bogs	**0%**
		Maritime wetlands	Intertidal flats	**0%**
			Salines	**0%**
			Salt marshes	**9%**

The Table 2 shows that almost all classes can be found in most of the scenes. It is due to the large size of the scenes (75km x 75km).

We calculate the NDVI average in all of these classes and we compare them to the value selected by a visual interpreter as the optimum vegetation-non vegetation threshold [11] (VI-reference).

According to the analysis into the *Agricultural areas* class of the CLC, the NDVI values are always much higher than the VI-reference. The values of the class *Artificial surfaces* are often lower than the VI-reference. The NDVI values measured in the class *Forest* are often higher than the VI-reference. The 2nd level of the CLC does not denote a clear correlation with the VI-reference. In the 3rd level of the CLC a class is defined and named "Green urban areas". This class is the one we are interested in, but it shows always higher values than the VI-reference.

The average NDVI values calculated into the "Discontinuous urban fabric" class, defined as an urban mix "discontinuous" of houses, streets, green and terrain, is consistently closer to the VI-reference among all the 30 classes. This class belongs to the 1st level class "Artificial surfaces", together with the "Green urban areas" (that contrary to what one might expected is not the most representative class). The discontinuous urban fabric is present in more than 80% of the scenes. <u>The rationale for the automatic processing has been modelled using this result defining three hierarchical possible scenarios</u>.

2.3. The model

The model is based on a pseudo NDVI named NDVIx. We calculate a threshold using a different value in each scene. Over selected classes of the CLC we calculate the mean and standard deviation of NDVIX pixels which falls in that location. According to the presence or absence of specific classes we define different scenario. The classes where statistics are collected aree: "Continuous urban fabric", "Discontinuous urban fabric", "Industrial or commercial units".

The three scenarios used are:

- Scenario 1: Presence of the class "Discontinuous urban fabric". This is the best scenario, because the average of the NDVI in this class is the closest to the threshold defined manually.
- Scenario 2: Absence of the class "Discontinuous urban fabric", presence of "Continuous urban fabric" or "Industrial or commercial units". This is the second best possibility, because the average NDVI derived here represents the second best threshold.
- Scenario 3: Absence of the classes "Continuous urban fabric", "Discontinuous urban fabric", "Industrial or commercial units". This scenario is rare and denotes the absence in the reference of urban typologies, so it can be considered out of domain. Even though, we define it and calculate the average NDVI. The zones in this scenario are: "Open spaces with little or no vegetation" and "Scrub and/or herbaceous vegetation associations".

The different scenarios are used to determine the thresholds as follow:

$$\mathrm{mm} = \mathrm{mean}\big(\mathrm{NDVIx}(\mathrm{Scenario})\big)[13]$$

$$\mathrm{sm} = \mathrm{std}(\mathrm{NDVIx}(\mathrm{Scenario}))\,[14]$$

$$\mathrm{Threshold} = \mathrm{mm} + \mathrm{sm}\,[15]$$

The vegetation layer (VEG) is calculated as follow:

$$\mathrm{VEG} = \mathrm{NDVIx} > \mathrm{Threshold}\,[16]$$

The VEG layer is a binary dataset with the same size and resolution of the input image. Pixels with value 1 represent green, pixels with value 0 are not green (*see Figure 3*).

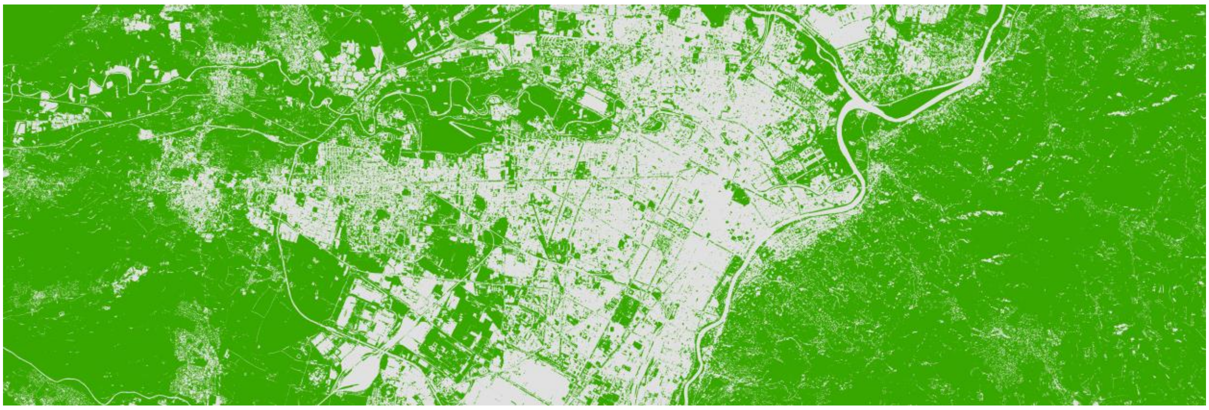

Figure 3 - VEG layer (Torino)

2.3. Classification

In the workflow the VEG layer is integrated in the ESM following a hierarchical procedure. To explain the hierarchy, we have to briefly introduce the other components (features) that make up the ESM: the texture component (PANTEX [1]) and the morphological component (CSL [2]). More details can be found in [3, 7].

An example of the three feature (PANTEX, CSL-Saliency, VEG) are in Figure 4 respectively named as a, b, c. The area shown in Figure 4 is the city of Torino (Italy). All the three feature have a resolution of 2.5m. Figure 4-a and Figure 4-c are shown at 1:40k scale to give a compressive overview of the entire city, Figure 4-b is shown at 1:20k to make visible the buildings shape.

The PANTEX (see *Figure 4-a*) is a built-up area presence index used to distinguish urban area. It has continuous value ranging from 0 to 1. In the figure it is represented with a grey scale colour ramp where black is 0 and white is 1. The Saliency (see *Figure 4-b*) is an output of the morphological decomposition of the image CSL, it is the intermediate feature containing the buildings, its values are integers, and as the PANTEX is represented with a grey scale colour ramp where black is 0 (no buildings). VEG (see *Figure 4-c*) is the vegetation layer derived from the NDVIx, it is binary (0/1) where 0 means no-vegetation (light grey) and 1 is vegetation (light green).

These three main components are mixed to obtain one classified layer.

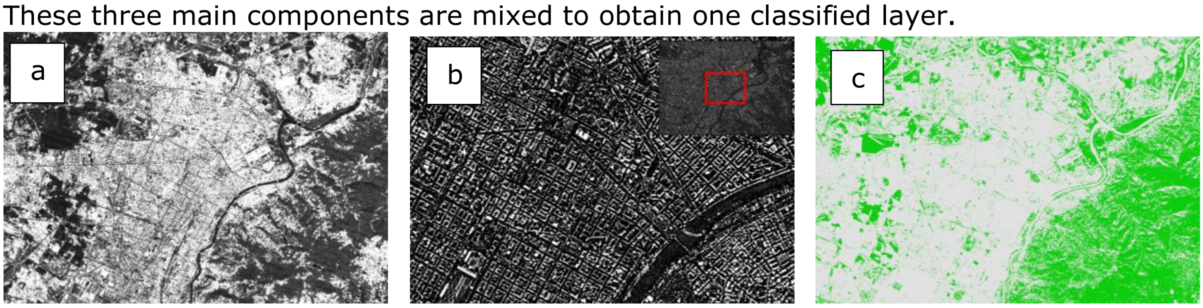

Figure 4 - Features

2.3.1 Classification sequence

Firstly, we define and distinguish the built-up area (BU Area) from the non-built-up area (NBU Area) applying a threshold to the PANTEX (*Figure 5-a*); in blue the built-up, in pink the not-built-up.

Secondly, we overlay the VEG on two built-up not-built-up zones two zones, defining the vegetation in built-up (BU Area–Green NDVIx) and the vegetation out of the built-up (NBU Area–Green NDVIx) (*Figure 5-b*).

Thirdly the buildings from the CSL Saliency are added to the map (*Figure 5-c*).

The remaining spaces (blue and pink) are respectively classified as Open Space in Built-up (BU Area–Open Space) and Open Space out of Built-up (NBU Area–Open Space) producing the complete classification (*Figure 5-d*).

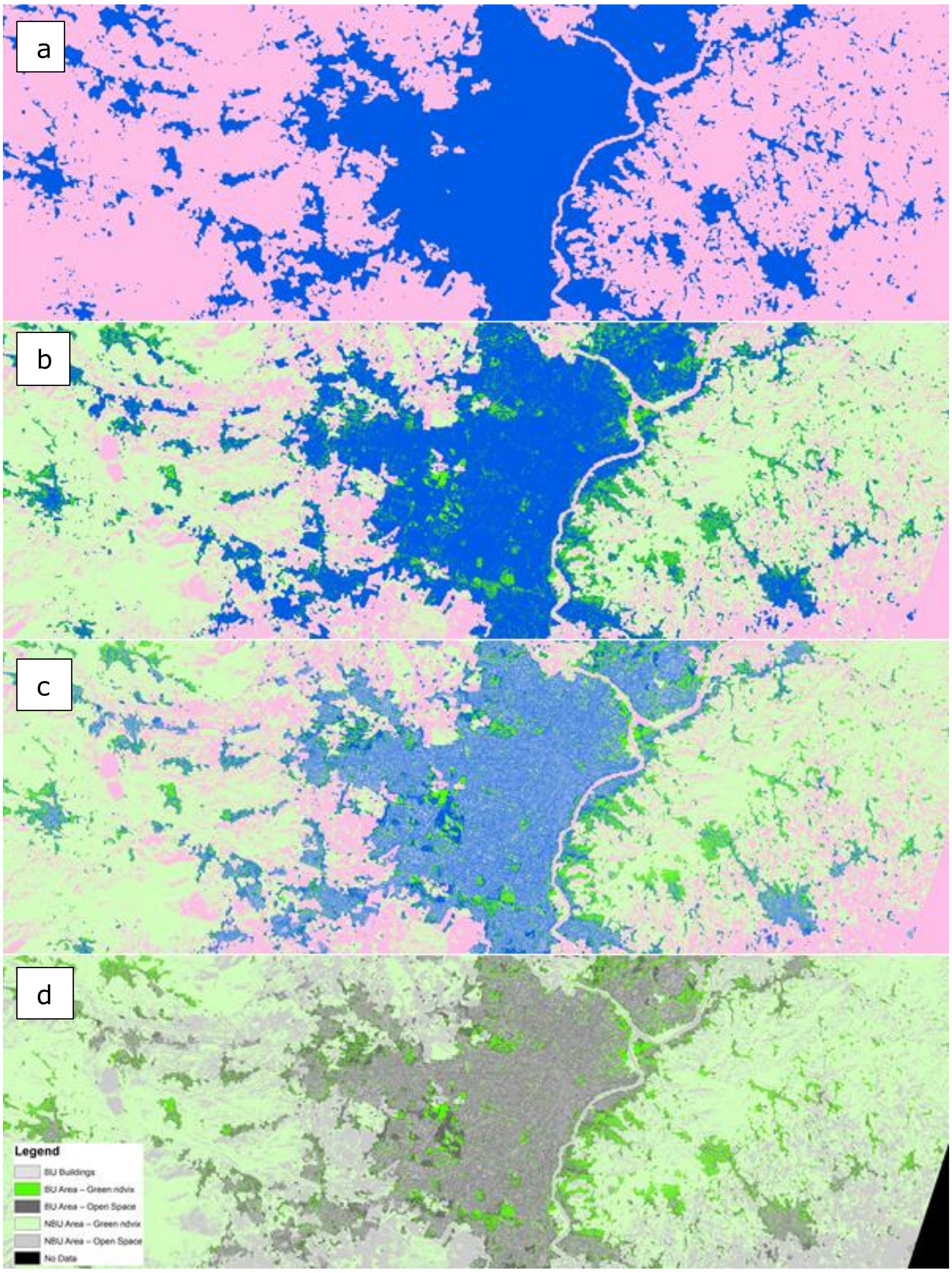

Figure 5 - Classification sequence, Torino (Italy)

The built-up is the last input in the sequence and it has the highest priority. Consequently, the classification of the green can be modified in the final step of the model. Benefits and disadvantages of this approach are addressed in the technical report on the ESM green quality assessment [12]. This approach is characteristic to the GHSL method, which aims at built-up detection.

Table 3 shows the raster classes, respective values (0-5) and BU/NBU macro class.

Table 3 *. ESM 6 classes definition and Raster Value*

ESM Raster Value		Description
BU	5	BU Buildings
BU	4	BU Area–Green NDVIx
BU	3	BU Area–Open Space
NBU	2	NBU Area–Green NDVIx
NBU	1	NBU Area – Open Space
0	0	No Data

2.3.1. External reference dataset integration – impact on GREEN

The availability of consistent external reference information allowed to develop a post-processing script for the ESM. It reprocesses the classified ESM, applies masks, redefines the shape of the buildings and adds new classes.

The external reference data used are: (i) buildings from national cadastral dataset and buildings from OpenStreetMap; (ii) streets, railways and inland water from TomTom; and (iii)Street Area and Urban Green from Urban Atlas.

Buildings from external reference impact on green because they are introduced in the layer complementing the BU Building class and according to their priority they can modify pre-existing classification.

The NBU Area–Green NDVIx and BU Area–Green NDVIx pixels are masked and reclassified in new classes, if their area overlaps the water (blue) or railways (black) (*Figure 6*).

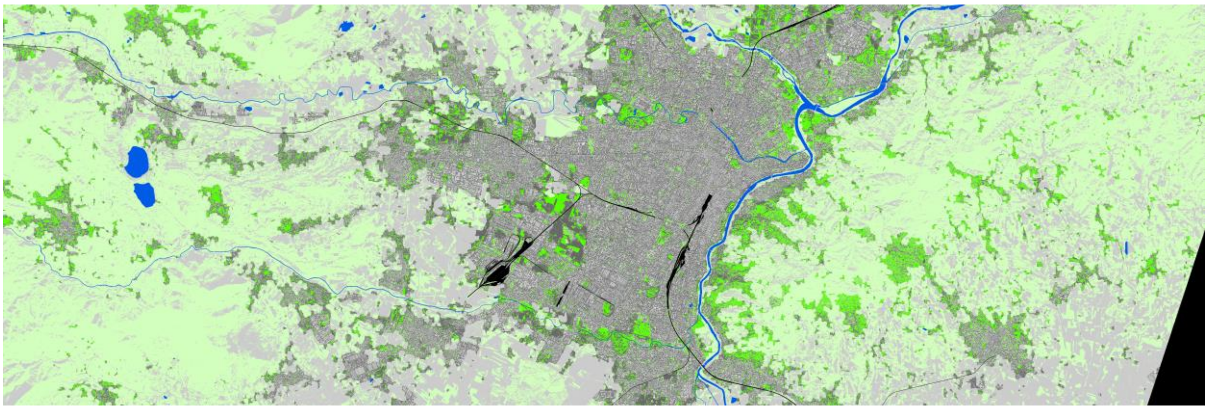

Figure 6 - ESM masked with Water and Railways

2.3.2. Street Green

In the case, that any VEG pixel (either in BU or NBU), overlays streets, it is converted in one of the following classes:

- $\text{BU Area– Green NDVIx} \cap \text{Streets} = \text{BU Area– Street Green NDVIx}$
- $\text{NBU Area– Green NDVIx} \cap \text{Streets} = \text{NBU Area– Street Green NDVIx}$

In Figure 7 street pixels (red) intersect the Green NDVIx.

Figure 7 - ESM Street Green

2.3.3. ESM and Urban Atlas (Urban Green) fusion

Among all the reference dataset, the Urban Atlas (UA) is the only one which Urban Green (UG) class can complement the ESM. The UG class is defined as "*parks or green urban areas not necessarily fully vegetated but with the urban function"*[13]. The ESM pixels that overlay the class Urban Green of UA are reclassified as: BU Area – Urban Atlas Green

- $\text{BU Area– Open Space} \cap \text{UG} = \text{BU Area– Urban Atlas Green}$

Figure 8 shows an example where UA pixels (red) have been reclassified according to this rule.

Figure 8 - ESM Urban Atlas (Urban Green) Integration

As a result, this process can complement some holes in park areas. The advantage of this approach is that it maintains the VEG component recognizable. The integration of external reference in the ESM required changing the ESM Raster Value (0-50) to allow adding new class values. In the *table 3* the new classification is showed

***Table 4** . ESM 13 classes definition and Raster Value*

ESM Raster Value		Description
BU	50	BU Buildings
BU	45	BU Area–Street Green NDVIx
BU	41	BU Area–Urban Atlas Green
BU	40	BU Area–Green NDVIx
BU	35	BU Area–Streets
BU	30	BU Area–Open Space
NBU	25	NBU Area–Street Green NDVIx
NBU	20	NBU Area–Green NDVIx
NBU	15	NBU Area–Streets
NBU	10	NBU Area–Open Space
	3	Airports
	2	Railways
	1	Water
	0	No Data

3. Mosaic

The ESM's procedure/method processes images at the resolution of the input scene (2.5 meter). It processes each of the 3,800 scenes separately, and produces 3,800 output images.

Each output image is one-layer TIFF encoded with values ranging from 0 to 50. it maintains the same number of pixels and geographical position of the input scenes. The

```
gdalbuildvrt -a_srs "EPSG:3035" -srcnodata 0 -vrtnodata 0  index_2p5m.vrt *.tif [17]
```

outputs have a very small scene overlap. The output mosaic at 2.5 meter is obtained using a VRT which allow maintaining the 3800 output unaltered.

The hierarchy in the overlay is solved by sorting the images by acquisition date (i.e., the newer image on the top), and according to this rule, the files list sequence is prepared and then the VRT. The library used is GDAL, with the command "*gdalbuildvrt".*

3.1. Aggregation

In order to facilitate the study of a single component of the ESM, we produced a set of 10-meter mosaics. Each ESM's scene has been split by class, obtaining 13 Boolean layers (presence – absence of the selected class). The Boolean layers are aggregated at 10m (using average as aggregating operator). Finally, they have been stacked into

one file.

```
%aggregation and stack creation
%geographical information of the source 2.5m
geoinfo = geoiminfo([* '_2p5m.tif']);
%geographical information of the output 10m
out_geoinfo = geoimscale(geoinfo,10);
%nodata mask
mask_res = imresize(single(OUTtemp == 0),[RasterYSize,RasterXSize],'box');
mask_res = mask_res > 0;
%water mask
water_mask = imresize(single(OUTtemp == 1),[RasterYSize,RasterXSize],'box');
water_mask = water_mask > 0;
% CODE is a vector which contains the list the classes
for v = 1:length(CODE)
        c = OUTtemp ==CODE(v);
        resized = imresize(single(c),[RasterYSize,RasterXSize],'box');
        resized = int8(resized * 100);
        resized(mask_res) = 0;
        if ~(CODE(v) == 1)
                resized(water_mask) = 0;
        end
        c = 0;
        if v == 1
                OUT = resized;
        else
                OUT = cat(3,OUT,resized);
        end
                resized = 0;
end
geoimwrite(uint8(OUT),outfile, out_geoinfo);
```

We used the VRT as done for the 2.5m mosaics to produce the 10m mosaics.

At 10 meter we obtain in total 13 mosaics, 5 of which are green mosaic:

1. 10m Mosaic of BU Area–Street Green NDVIx (index10m_45.vrt)
2. 10m Mosaic of BU Area–Urban Atlas Green (index10m_41.vrt)
3. 10m Mosaic of BU Area–Green NDVIx (index10m_40.vrt)
4. 10m Mosaic of NBU Area–Street Green NDVIx (index10m_25.vrt)
5. 10m Mosaic of NBU Area–Green NDVIx (index10m_20.vrt)

Conclusion

The main advantages of the ESM dataset are its coverage, resolution and metrics. Its green components inherited these characteristics. In this report we have illustrated the method which includes assumptions derived from empirical evidences. Further research is needed to analyse and extend the proposed approach.

Other existing datasets such as CLC and UA do not have the two main characteristics that are needed to study this urban component at regional level. The CLC has a good coverage but low resolution (100m), and the UA has a good resolution (minimum mapping unit 0.25 ha), but it covers only a certain number of cities in Europe.

The ESM green layers have both a European coverage and a higher resolution (2.5m) comparing to the other products. This characteristic make the layer usable in the studies that requires urban green at urban scale.

Figure 9, Figure 10 and Figure 11 show an example of the different resolution of these datasets are showed.

In Figure 9 the city of London and the Urban Green derived from the CLC.

Figure 9 - CLC Urban Green in London

The figure below shows the same area in the UA and demonstrates that UA, where available, can give more information than CLC. With a minimum mapping unit of 0.25 hectare it can better represent green in urban area (*see Figure 10*).

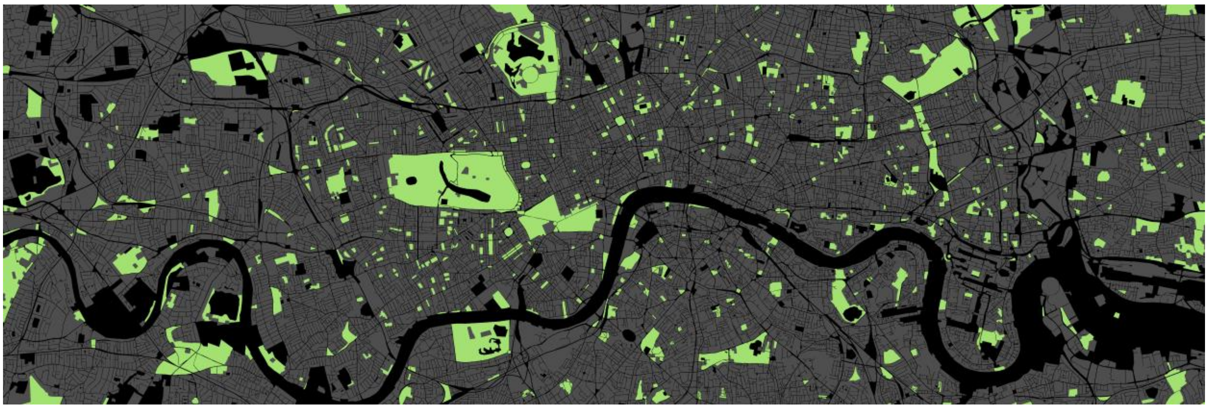

Figure 10 - UA Urban Green in London

The ESM green has the European extent of the CLC and a higher resolution than the UA. It allows increasing the capacity of detection and classification. The minimum mapping unit of the ESM is 0.0006 hectares (6.25 square meters) (*see Figure 11*).

Figure 11 - ESM green in London

Finally, overlaying streets and green we get the ESM class Street Green (*see Figure 12*) which highlights greenways of a city.

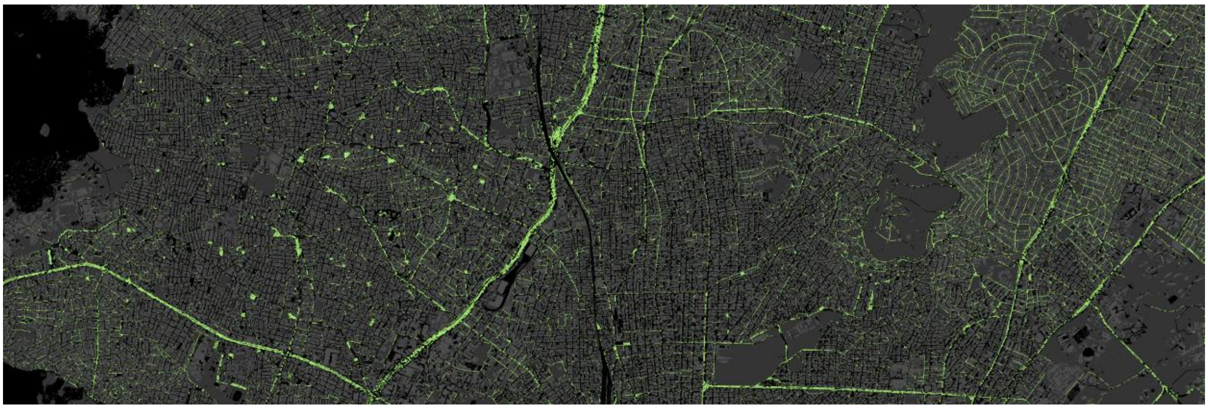

Figure 12 - ESM Street Green in Athens

The European Union finances instrument supporting environmental, nature conservation and climate with the project LIFE. Numerous LIFE projects focus on landscape protection, land-use development and spatial planning, including urban design and transport planning.

Another European project is the European Green Capital project: *"Urban areas are the source of many of today's environmental challenges – not surprisingly, since two out of three Europeans live in towns and cities. Local governments and authorities can provide the commitment and innovation needed to tackle and resolve many of these problems. One of the policy tools the European Commission is using to address these challenges is the European Green Capital Award (EGCA), which recognises and rewards local efforts to improve the environment, the economy and the quality of life in cities. The EGCA is given each year to a city, which is leading the way in environmentally friendly urban living and which can thus act as a role-model to inspire other cities. Cities differ enormously and sharing concrete examples of what a European Green Capital can look like is essential if further progress is to be made".*

Moreover, as reported on the European Commission [1]: *"European Commission has, in recent years, been increasing its focus on urban issues, as a response to the fact that by 2020 it is estimated that almost 80% of EU citizens will be living in cities. The political importance of the issue is demonstrated by its inclusion in the 7th Environmental Action Programme (7EAP) under Priority Objective 8, entitled, Sustainable Cities: "Working together for Common Solutions". The overall objective of this policy drive is to enhance the sustainability of EU cities to achieve by 2050 that all Europeans are "living well, within the limits of the planet".*

Fine scale and urban focus, make the ESM green a valid input for European projects that need information over all European countries and enough details that permit studies at urban scale.

Many assumptions in the method described are derived from practical experience and test on a few samples.

The *formula* [2] has already been used in publication for built-up detection but its numerical advantage/disadvantage metric that has never been assessed systematically on a big dataset like the one used for the ESM elaboration.

The *formulas* from [2] to [12] are an experiment that has been set up to overcome the problem of missing information (parameters) of the gain and offset for all bands.

The domain where to look for the thresholds *formulas* [13] to [16], and the decision to use the mean plus one standard deviation metric *formula* [15] have been studied on 100 sample image (2.63 % of the total) and visually evaluated on 3 images.

The collection of statistically significant reference data for the quality assessment is on-going. It is done by a visual interpreter that manually (visually) collects and classifies reference Area of Interests (AOI) using very high resolution.

[1] http://ec.europa.eu/environment/urban/index_en.htm

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List of abbreviations and definitions

7EAP	7th Environmental Action Programme
AOI	Area of Interest
b-GREEN	Band GREEN of images from the Copernicus 003 dataset
b-NIR	Band NIR of images from the Copernicus 003 dataset
b-RED	Band RED of images from the Copernicus 003 dataset
BU	Built-up Area according to the PANTEX
CLC	Corine Land Cover 2000 dataset
CSL	Characteristic Saliency Levelling
DG REGIO	Directorate-General for Regional and Urban Policy
EGCA	European Green Capital Award
ESM	European Settlement Map
GHSL	Global Human Settlement Layer
L	Luminance
LIFE	Programme for the Environment and Climate Action (LIFE) and repealing Regulation (EC) No 614/2007
NBU	Built-up Area according to the PANTEX
NDVI	Normalized Difference Vegetation Index
NDVIx	Pseudo Normalized Difference Vegetation Index
PANTEX	Textural measure
SDG	Sustainable Development Goals
UA	Urban Atlas Layer
UG	Urban Green Class of the Urban Atlas Layer
URBA	JRC URBA Project
VEG	Vegetation layer derived from the NDVIx
WPK Id	European Commission - Joint Research Centre, Work Package Id

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